Tree-ring radial-growth relationships to summer temperature across a network of sites in eastern Labrador

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Abstract

Eastern Labrador rests at a crucial point geographically and climaticoligically. The polar front passes over eastern Labrador, it is highly affected by the Icelandic low, and it is near the intersection of the Gulf Stream and the Labrador Current. These climate factors underscore the need to study the effect and extent of maritime influences on the adjacent Labrador forests. The reality of a short and geographically limited climate record in the region emphasizes the need for a secondary method to analyze past and future climate signals held within these forests. This study uses a dendroclimatological analysis to observe the extent of the maritime influence on radial growth of conifer species in southeastern Labrador. We sampled ten sites in a systematic grid consisting of three north-south transects and four east-west transects. Nine chronologies of black spruce (*Picea mariana*), nine chronologies of balsam fir (*Abies balsamea*), one chronology of both white spruce (*Picea glauca* (Moench) Voss) and eastern larch (*Larix laricina* (Du Roi)

K. Koch) were developed from the dominant species preset at each node. Pearson product moment correlations and response function analyses were utilized to identify two distinct zones of radial growth-climate relationships within the study area. We identified the maritime zone, characterized by strong sensitivity to July temperatures, and a negative response to August and September mean temperatures, as extending further eastward than previously defined in the literature. In the extreme coastal regions, we now define another type of radial growth-climate relationship. This hyper-maritime zone is characterized not only by a strong positive association to July temperatures, but also by positive relationships to August and September growing season temperatures. These results illustrate that there is a strong growth-climate gradient from east to west passing through at least three distinct zones in southern Labrador.

Introduction

As noted by Vincent and Gullett (1999), northern climate stations are sparse in spatial extent compared to more southern regions and they also cover a much shorter time span. With scant instrumental records available, it is often necessary to develop proxy records in order to gain a better understanding of past climates as they relate to ecological processes (Delworth and Mann, 2000), especially in these northern areas where the most drastic changes in climate have been recently noted, and are predicted to continue to occur (Raisanen, 2001, Hassol, 2004, Johannessen et al., 2004, Chapin et al., 2005,Trenberth et al., 2007).

In Newfoundland and Labrador, Jacobs and Banfield (1998) illustrate the variability in climates to be influenced by three main forcings: The Canadian polar trough, which exerts control over the polar and arctic fronts; the size and position of the Icelandic low pressure area contrasted to the Bermudan sector of the North Atlantic subtropical anti-cyclone; and the offshore sea ice cover and extent. These three factors are all closely linked to maritime conditions, this and other studies (e.g., D'Arrigo et al., 2003, Sutton and Hutson, 2005) help to underscore the need to understand the intensity and spatial extent of the maritime influences on Labrador climates. In their analysis, Banfield and Jacobs (1998) use only Cartwright and Goose Bay climate stations as their instrumental data sources within Labrador. These two relatively short and spatially distinct station records leave much of Labrador's regional climate unexplored and poorly defined.

Researchers have tried to illuminate weaknesses in paleoenvironmental and paleoecological conditions of Labrador, specifically by using tree rings as an indicator of past conditions. But similar to the climatological studies, the dendrochronological research in Labrador has been very localized and has left much of the region unexplored. Early studies concentrated their efforts in a few locations in the northeastern region of Labrador (e.g., Cropper and Fritts, 1981, D'Arrigo et al., 1992, Schweingruber et al., 1993, and Briffa et al., 1994). These studies, although useful, lacked a larger scale comparative perspective that newer studies have incorporated in their design (e.g., Payette, 2007, Trindade, 2008, Nishimura, 2009), which better assist in unraveling many of the complexities of the climate and ecology in the Labrador region.

Payette (2007) was first to illustrate a shift in dendrochronological studies in the region from a single point study to more of a larger regional assessment. This study was also the first to identify a shift in tree responses between coastal and inland regions of Labrador. The study focused on northern Labrador's latitudinal treeline from the coast into the adjoining province of Quebec. It found a distinctive difference between the inland white spruce (*Picea glauca* (Moench) Voss) treeline, which has receded over the past centuries (Lamb, 1985, Payette, 2007), and coastal locations where the treeline had advanced. Payette (2007) attributed this to both climate changes and bio-geographical influences in a post glacial landscape.

Trindade (2008) followed this research by illustrating a shift of sensitivities between tree-ring radial-growth and associated climates of central Labrador. The study found changes on both a spatial and temporal basis, tied closely to the proximity of a tree's location to the coast. The study utilized a longitudinal transect extending from coastal Labrador near Cartwright and reached westward as far as Labrador City, 670 kilometres to the west.

Western Labrador was then extensively investigated by Nishimura (2009). The study used a distinct spatial network of dendrochronological sites, creating a grid of north-south and east-west transects covering all of western Labrador. The results of this study illustrate a transitional shift in the climate-tree ring relationship as one moves further westward from coastal influences. In particular the study delineates a transition zone from maritime to continental climates in an area void of any long-term instrumental climate stations, by using the ecological signal found within tree rings. The question remaining to be answered from this study was whether the central Labrador maritime zone identified, continues eastward all the way to the Labrador Sea (Nishimura, 2009)?

The main purpose of this study is to investigate this question, by better understanding the spatial nature in the radial-growth characteristics of the tree-ring and climate relationship of the dominant conifer species in southeastern Labrador. By doing so, this study tries to better understand any spatial shifts in the climate sensitivity of the trees at a greatly refined and contiguous scale than previous studies have attempted along coastal Labrador. It also endeavors to better delineate any shift in the influences of the maritime effect by continuing a gridded transect sampling method in both an east-west and a north-south fashion adding to the network started by Nishimura (2009). This sampling protocol was conducted to better illustrate any spatial shifts in dimensions previously unseen in the regions instrumental record, and also to join into the established gridded tree-ring system of Labrador.

Study Sites

A systematic gridded sampling protocol was applied across the entire eastern portion of Labrador in order to facilitate a more refined spatial analysis than has been previously attempted. Each site was selected at the closest accessible point at the intersection of 52, 53, 54, and 55 degrees north latitude and 56, 58, and 60 degrees west longitude (Figure 1, Table 1). A similar methodological framework and spatial resolution was applied in western Labrador by Nishimura (2009). Two nodes at the intersections of 54 and 55 degrees north latitude, with 60 degrees west longitude rested over the Labrador Sea and were eliminated from a completed grid square leaving only the remaining 10 nodes on land to be sampled (Figure 1).

Each node was labeled according to their position in the grid. The nodes were labeled by column, with a "W" designation used for the most westerly sites along 60 degrees west longitude, a "C" used to designate the central column of nodes along 58 degrees west longitude, and an "E" used to designate the most easterly sites along 56 degrees west longitude. In the north-south direction, a numerical system was applied. The most northern row of nodes were designated as 1, and then each row was sequentially numbered until the most southern row, which was labeled as 4 (Figure 1).

Methods

At each node, the two most co-dominant tree species were selected and sampled. Two increment cores were extracted at breast height from 20 mature trees from each species for a total of 40 cores per species, 80 cores per node. The cores were brought back to the Mount Allison Dendrochronology Laboratory, glued into slotted mounting boards, sanded to a fine polish, and visually checked for a shared radial-growth pattern. The total annual ring widths were then measured with a Velmex system to the nearest 0.001 mm, and then crossdated. The rings were statistically evaluated using COFECHA (Holmes, 1983, Grissino-Mayer, 2001). Each chronology was then standardized with ARSTAN using a single detrending negative exponential curve to fit each series (Cook 1985; version ARSTAN_41d). DENDROCLIM2002 (Biondi and Waikul 2004) was then used to run a response function analysis on each chronology. DENDROCLIM2002 uses bootstrapped correlations to analyze the annual radial growth response to climate factors that may be influencing radial tree growth (Biondi and Waikul 2004). A DENDROCLIM2002 analysis was run using a monthly analysis window of 18 months. The window starts in April of the previous year (t-1) and ends in September of the growth year (t-0).

Climate Data

There was one long-term climate station present within the gridded network and one adjacent to the study area. The two Environment Canada stations are located in Cartwright (within grid) and Goose Bay (adjacent to grid) (Figure 1). The common interval of record for the two climate stations is 65 years from 1942 to 2006. Figure 2 illustrates mean monthly temperature of both the Cartwright and Goose Bay climate stations. Due to its relative inland location, Goose Bay illustrates higher average summer temperatures and a sharper decline in colder temperatures from August to December, than what is recorded at the Cartwright station due to the influence of the adjacent Labrador Sea (Figure 2).

Although other known stations are within the greater region (Hopedale - on the coast approximately 50 km north of node C1; St. Anthony - on Newfoundland's Northern Peninsula approximately 70 km south of node E4; and Battle Harbour - approximately 30 km north of node E4 and 80 km south of E3), these records are short and several of the stations have been moved throughout their existing record. For these reasons, the Cartwright and Goose Bay station records were the only ones used for climate analyses.

Results

Of the 20 dominant trees species chronologies constructed, nine were black spruce (*Picea mariana* (Mill.) B.S.P.), nine were balsam fir (*Abies balsamea* (L.) Mill.), one was white spruce, and one was eastern larch (*Larix laricina* (Du Roi) K. Koch) (Table 1). The average length of the entire sample population was 110.6 years, with the eastern and coastal nodes tending to be much younger than those farther inland (Table 1). Master chronologies from nodes C1, C4, E3, and E4, had particularly short spans. Of these four nodes, the average age of the increment cores was only 78 years. The remaining six inland nodes were older, at an average age of 130 years.

Correlation analyses

Table 2 illustrates the results from an inter-series Pearson's product moment (r) correlation matrix between all 20 chronologies. Most nodes in the western and central locations illustrate strong correlations to each other. The strength of the significant positive correlations ranges across the grid from an r-value of 0.22 to an r-value of 0.88 (n=89, all values above .208 are p>0.05). In general, the correlations that do not meet the 95% level of significance exist between species, and generally, are separated by a good distance spatially. The matrix illustrates strong correlations between most chronologies at most nodes (302 of the 361 r-values demonstrate significant r-values at the 95% level). Many of the 59 non-significant r-values between chronologies can be identified by inter-species comparisons (36 of 59); however there were also some non-significant correlations between the nodes along the coast and those further inland for the same species (14 of the remaining 23). This leaves only nine relationships out of the total of 361 possibilities that either did not reach the 95% significance interval or that were not explained by one of the two explanations above. These results illustrate that there is a fundamental similarity in 84% of the growth patterns of all of the chronologies, with most of the other difference seen in distance from one site to the other and across species. In light of this, we conducted a response function analysis to try to better understand the most likely over-riding effect on radial tree growth, climate.

Response Function Analyses

Table 3 illustrates the significant relationships (95% confidence) between the 20 chronologies and the Cartwright data set for temperature over the 18 months tested. Within the growth response analyses, only one variable is consistently characterized as having a significant relationship between radial growth and mean monthly temperatures in eastern Labrador, July temperature of the growth year (20 of 20 chronologies) (Table 3, Figure 2). To tease out a more subtle expression of the climate radial growth relationship, the same procedure was repeated, but the significance threshold was raised to the 99% level (Table 4).

Again the strongest climate radial-growth signal in eastern Labrador was the relationship between annual radial growth and July temperatures of the current growth year, but a separation in this signal also became evident. All of the spruce and fir chronologies in the western column displayed significant correlations to July temperature excluding the fir at W3. In the central column, spruce was significant at the 99% level at C2 and C3, while fir exhibited significant correlations at C1 and C3. In the eastern column there were no significant results to the 99% significance level.

Discussion

Correlation analysis

The results of the study illustrate that two regions of radial growth exist for black spruce and balsam fir in eastern Labrador. The maritime effect as outlined by Nishimura (2009) (positive relationship to July temperature, negative relationship to August and September temperature) is apparent in all sites, except the easternmost coastal nodes which convey a different growth characteristic. Specifically sites C1, C4, E3, and E4, illustrate a distinct signature of influence consistent with a more hyper-maritime climatic effect.

The first indication of the hyper-maritime effect is evident in the eco-regions, where E3, E4 and C1 are all in coastal barren zones (see Table 1) (Roberts et al., 2006). Along with eco-region plant assemblages, a distinction was found in the stand ages. During sampling, one of the criteria was to seek the most mature trees that could be found in the stands. The data illustrated that the most eastern and coastal sites had distinctly younger trees (Table 1). There are several possible causes for this division in the data. The first is the general lack of protection near the open sea. The stands in the hyper-maritime zones tended to be found in lower lying areas surrounded by barons. Black spruce in particular grows in valleys when it is near its climatic tolerance and seed regeneration tends to be more sporadic (Payette, 1982). With little protection from harsh weather condition due to smaller stands constrained mostly to valley bottoms, trees may not have the chance to mature to the stage observed at the inland sites. Younger stand ages may also be related to the possibility of slow and unpredictable development of forested regions in a post glacial landscape freshly emerging from isostatic uplift (Scott et al., 1987).

C4 is included in this hyper-maritime group as it did not correlate as well against the inland nodes. Although the site was not in the same proximity to the coast as the other three sites that we designate as hyper-maritime (C1, E3, and E4), the surrounding area shared similar characteristics to those along the coast. C4 is within a low subarctic tundra ecoregion which contains similarities to the coastal baron region. Sampling was conducted in a small stand on low lying land similar to the sampling conducted at the other nodes in the hyper-maritime zone. The surrounding area was barren and the stand was sparsely populated leaving the trees susceptible to exposure from hash conditions. The growth response analysis, discussed subsequently, also demonstrates that C4's growth response to mean monthly temperature matches more closely to the other hyper-maritime nodes.

Response Function Analysis

The growth response analysis identified trends similar to those in other parts of central and western Labrador. The maritime zone, identified by Nishimura (2009) as being firstly characterized by a strong growth response to July mean temperature, was present at all nodes (Table 3, Figure 2). This growth response to July temperatures has also been identified in most Labrador studies (e.g., D'arrigo et al., 1996, 2003; Payette, 2007 ; Trindade 2009). The coastal, hyper-maritime sites shared this sensitivity to July temperatures but also exhibited growth response characteristics that set them apart from this classic maritime effect.

When the higher significance threshold of 99% was used to analyze July growth responses, a distinction could be drawn between the hyper-maritime nodes and the classic maritime nodes. The classic maritime nodes exhibit significant relationships at all spruce nodes and four of six fir nodes. The only hyper-maritime node to express a very strong relationship to July mean temperature at the 99% significance level was fir at C1. This distinction helps to illustrate the more muted response of radial growth to July temperatures within the hyper-maritime zone when compared to the maritime zone.

With the exception of spruce at W1, mean monthly temperature in August of the current year of growth illustrated a negative trend to radial growth in the western column for both spruce and fir, the second fundamental characteristic outlined by Nishimura (2009) for the maritime effect. Again in the central column of sites, near zero or negative trends to August temperature was found at both sites we label as maritime (C2, C3). At the other two sites in the central column that we label as hyper-maritime, as well as at the two eastern nodes, all species switch to a positive trend in the response to August mean temperatures, particularly with fir. Although none reached the 95% significance level, the dramatic reversal in signal is distinct.

At the four hyper-maritime nodes, there was a measureable drop in the growth response signal from July mean temperature to August mean temperature, but the sites did however maintain a positive trend. This is converse to the classic maritime sites which generally exhibit a negative trend to radial growth during the warmer August growing conditions found to the west (Figure 2). The reduced growth response appears to be in reaction to the higher temperatures found in August at inland sites, while maintaining a similar moisture regime to July.

Precipitation amounts between Goose Bay and Cartwright stations can exhibit a fair amount of variation during summer months (Foster, 1983) and August temperatures at Cartwright are on average 2.3 °C lower than temperatures at Goose Bay which is significantly more inland than the Cartwright station. This reduced growing season temperature allows the trees to continue to grow radially, while others at more inland sites probably cross a moisture-related threshold and halt their radial growth for the year.

Tree radial growth responded to September mean monthly temperatures with similar results as August at nodes we designate as hyper-maritime. Overall, the designated hyper-maritime nodes responded quite positively to September temperatures. All fir nodes even exhibit relationships with significance levels over the 95% confidence interval except at C1, and nodes with spruce illustrated a consistently positive trend. The inland central sites (C2 and C3) and all of the western trees generally reacted indifferently to September mean temperature with near zero or negative relationships illustrated, with the exception of black spruce at W1.

When this new data is combined with the previous information defined by Nishimura (2009), a more complete picture of radial growth-climate relationships for trees in southern Labrador comes into focus (Figure 4). From the Quebec border to an approximate zone running north-south near Churchill Falls lies the continental zone (Nishimura, 2009). This zone is distinguished by radial growth-climate relationships that are positive to May-June and June-July temperatures, and have a negative relationship to August temperatures. Moving eastward, the next zone is the maritime zone and it moves across southern Labrador from roughly Churchill Falls (Nishimura 2009), until the central column of nodes in this study (Figure 2 and 4). This zone is characterized by radial growth-climate relationships that are positive to July temperatures, but again have a negative relationship to August temperatures. The final area is the newly defined hyper-maritime zone. It too is defined by a positive relationship to July temperatures, but it switches in its relationship to late summer growing temperatures by also illustrating a positive relationship to August and September temperatures.

Conclusion

The spatial nature of conifer growth responses in Labrador is complex. This study identifies two distinct zones of growth response, the continuation of the maritime zone previously identified by Nishimura (2009) moving eastward and a newly proposed hyper-maritime zone identified in this network of nodes (Figure 4). The characteristics that define the hyper-maritime zone are young stands, contained mostly in costal barren eco-regions. The trees within the hyper-maritime zone are sensitive to July temperatures, but they also contrast the tree radial growth relationships in the maritime zone. The trees within the hyper-maritime zone also illustrate a positive radial growth response to August and September temperatures due to lower overall temperatures immediately adjacent to the coast throughout the growing season. This translates to an elongated growing season into September which is not seen further inland in Labrador. The longer growing season and younger stand ages observed in the hyper-maritime zone accounts for the larger annual growth increment in this region when compared to the nodes further inland (Table 1).

The gridded approach to sampling has provided a strong spatial analysis tool as yet unseen in the southeastern area of Labrador. Combined with the Nishimura (2009) data set, there is now the capability to observe trends in radial growth and ecological growth responses on both the refined spatial scale of specific areas of southern Labrador, as well as the more general scale of all of southern Labrador and adjacent areas of the province of Quebec. This information provides the opportunity to expand our knowledge and lend evidence to begin to answer questions such as: How will the continental, maritime and hyper-maritime zones of tree growth be affected under the projected changes in the climate of Labrador? With the continental and maritime nodes already exhibiting moisture stress from high August temperatures, will this period of stress expand to include the earlier climates in late-July and late-September? Will the hyper-maritime zone finally begin to experience a heat related stress caused by elevated mid-summer temperatures if growing seasons continues to warm, or will they continue to lag behind inland areas because of their connections to the influences of the cool Labrador Sea (Lazier, 1988)? With the zones of generalized tree-radial growth in southern Labrador finally better understood in regards to their relationship to climate, many new doors have suddenly opened for further study in southeastern Labrador's forests.

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Tables

Table 1 –The site details of each location and statistics relating the each crossdated master chronology. BS=black spruce; WS=white spruce; EL= eastern larch; BF = balsam fir. MSI = mean series intercorrelation (calculated on 50-year lagged segments); MTA = mean tree age; AMS = average mean sensitivity; AC=unfiltered auto-correlation; MM = mean measurement (annual increment). Eco-region: Based on Newfoundland and Labrador Department of Environment and Cconservation, Parks and Natural Areas Division (see website at http://www.env.gov.nl.ca/parks/apa/eco.html) (Roberts et al., 2006); HST = high subarctic tundra; LB = low boreal; HBF =high boreal forest; LSF = low subarctic barrens; CB = costal barrens; MB = mid-boreal forest; LST = low subarctic tundra.

Site	Site Name	Species	Latitude	Longitude	Elevation(m als)	Length of Chronology	No. of Cores	MSI	MTA	AMS	AC	MM	Eco-region
W1	Bush Pond	BS	54.8141°N	59.9345°W	28	1666-2007 (342)	36	0.534	156	0.198	0.803	0.43	HST
W1	Bush Pond	BF	54.8141°N	59.9345°W	28	1807-2007 (201)	33	0.504	113.8	0.195	0.788	0.43	HST
W2	Bug Tussle	BS	53.8849°N	60.0025°W	283	1751-2007 (257)	34	0.525	199.6	0.189	0.82	0.41	LB
W2	Bug Tussle	BF	53.8849°N	60.0025°W	283	1845-2007 (163)	34	0.47	117.3	0.205	0.723	0.43	LB
W3	Kenamu Lake	BS	52.9870°N	59.9483°W	357	1789-2007 (219)	38	0.495	122.2	0.176	0.733	0.51	HBF
W3	Kenamu Lake	BF	52.9870°N	59.9483°W	357	1855-2007 (153)	36	0.514	109.8	0.216	0.755	0.4	HBF
W4	Lac Betaux	BS	51.9458°N	59.9211°W	332	1803-2007 (205)	31	0.466	125.1	0.184	0.764	0.49	LSF
W4	Lac Betaux	BF	51.9458°N	59.9211°W	332	1871-2007 (137)	32	0.433	92.6	0.149	0.65	0.49	LSF
C1	Tanya's Tickle	WS	54.8042 °N	58.1885°W	4	1852-2007 (156)	38	0.541	97.9	0.258	0.695	0.8	CB
C1	Tanya's Tickle	BF	54.8042°N	58.1885°W	4	1789-2007 (219)	35	0.523	67.7	0.212	0.824	0.88	CB
C2	Mariana Lake	BS	53.0006°N	58.1401W	90	1746-2007 (262)	38	0.529	143.2	0.187	0.817	0.42	MB
C2	Mariana Lake	BF	53.0006°N	58.1401°W	90	1859-2007 (159)	35	0.514	112.9	0.189	0.788	0.45	MB
C3	Freeman's Pond	BS	52.9940°N	57.8402°W	236	1734-2007 (274)	34	0.452	147.4	0.187	0.763	0.4	MB
C3	Freeman's Pond	BF	52.9940°N	57.8402°W	236	1840-2007 (168)	30	0.495	110	0.183	0.7	0.5	MB
C4	Dumaresq Lake	BS	52.0440°N	57.9904°W	347	1858-2007 (150)	32	0.451	103.5	0.202	0.768	0.42	LST
C4	Dumaresq Lake	EL	52.0440°N	57.9904°W	347	1831-2007 (177)	33	0.498	104.1	0.298	0.767	0.65	LST
E3	Hawk Bay	BS	51.9805°N	55.9788°W	12	1837-2007 (135)	32	0.478	88.7	0.213	0.807	0.68	CB
E3	Hawk Bay	BF	51.9805°N	55.9788°W	12	1892-2007 (116)	33	0.465	81.8	0.209	0.861	0.61	CB
E4	Temple Bay	BS	51.9805°N	55.9025°W	20	1918-2007 (90)	33	0.483	61.5	0.214	0.727	0.88	CB
E4	Temple Bay	BF	51.9805°N	55.9025°W	20	1906-2007 (102)	33	0.487	56.5	0.198	0.853	1.13	CB

Table 2 - A matrix of Pearson correlation r-values between each radial growth chronology over an 89 year common interval between all chronologies (1918-2006). The cells highlighted in black are significant above the 95% confidence level.

	W1S	W1F	W2S	W2F	W3S	W3F	W4S	W4F	C1W	C1F	C2S	C2F	C3S	C3F	C4S	C4L	E3S	E3F	E4S
W1F	0.49																		
W2S	0.77	0.52																	
W2F	0.49	0.69	0.53																
W3S	0.45	0.59	0.74	0.55															
W3F	0.04	0.58	0.28	0.58	0.69														
W4S	0.40	0.67	0.58	0.56	0.76	0.50													
W4F	0.13	0.48	0.15	0.55	0.22	0.29	0.49												
C1W	0.36	0.38	0.22	0.24	0.40	0.37	0.19	0.11											
C1F	0.31	0.50	0.15	0.41	0.24	0.33	0.31	0.24	0.49										
C2S	0.80	0.58	0.85	0.46	0.66	0.20	0.58	0.20	0.32	0.24									
C2F	0.43	0.59	0.47	0.54	0.46	0.48	0.30	0.32	0.32	0.31	0.53								
C3S	0.63	0.63	0.84	0.58	0.88	0.56	0.77	0.19	0.33	0.27	0.78	0.45							
C3F	0.36	0.66	0.47	0.60	0.68	0.72	0.64	0.42	0.46	0.36	0.49	0.65	0.70						
C4S	0.41	0.31	0.63	0.20	0.70	0.31	0.50	0.02	0.33	0.06	0.58	0.19	0.72	0.43					
C4L	0.39	-0.02	0.26	0.08	0.11	-0.16	0.02	-0.15	-0.01	-0.04	0.32	0.19	0.13	-0.03	0.07				
E3S	0.36	0.40	0.18	0.26	0.28	0.14	0.30	0.33	0.53	0.35	0.45	0.32	0.23	0.30	0.25	0.15			
E3F	0.29	0.12	0.01	0.26	0.11	0.21	-0.07	0.10	0.56	0.44	0.14	0.42	0.06	0.29	0.08	0.25	0.54		
E4S	-0.08	0.23	-0.24	0.02	0.01	0.23	0.16	0.05	0.24	0.23	-0.10	-0.18	0.02	0.16	-0.02	-0.11	0.28	0.05	
E4F	0.02	0.27	-0.13	0.04	0.16	0.31	0.13	0.00	0.48	0.14	-0.07	0.08	0.16	0.34	0.27	0.04	0.24	0.35	0.43

Table 3 - The number of months that Cartwright's mean monthly temperature illustrated significant correlations to annual radial growth at a 95% significance threshold in a response function analysis performed by program DENDROCLIM2002. The cells highlighted in black have a positive relationship above the 95% confidence threshold. The cells highlighted in grey have a negative correlation above the 95% confidence threshold.

	W1S	W1F	W2S	W2F	W3S	W3F	W4S	W4f	C1W	C1F	C2S	C2F	C3S	C3F	C4S	C4L	E3S	E3F	E4S	E4F
APR T	-0.10	-0.26	-0.13	-0.09	-0.10	-0.19	-0.12	-0.12	0.02	-0.10	-0.12	-0.16	-0.16	-0.16	-0.15	0.01	-0.11	0.00	-0.10	-0.24
MAY T	0.02	-0.15	-0.03	0.11	0.04	-0.06	-0.02	-0.05	-0.06	-0.08	-0.13	-0.03	-0.02	-0.02	-0.10	0.09	-0.16	0.04	-0.19	-0.20
JUN T	0.07	-0.18	-0.05	0.03	0.04	-0.03	-0.01	-0.19	-0.12	0.08	-0.08	-0.11	-0.01	-0.11	-0.08	0.26	-0.05	0.00	0.05	-0.19
JUL T	0.37	0.21	0.32	0.24	0.34	0.20	0.35	0.10	0.00	0.21	0.34	0.03	0.37	0.19	0.23	0.21	0.22	0.07	0.14	0.04
AUG T	0.01	-0.31	-0.12	-0.12	-0.07	-0.13	-0.19	-0.29	0.00	-0.12	-0.17	-0.15	-0.10	-0.32	-0.05	0.29	-0.09	0.23	-0.05	0.08
SEP T	0.10	-0.20	0.00	0.04	0.04	0.04	-0.19	-0.32	0.22	-0.02	-0.16	-0.15	0.01	-0.15	0.10	0.40	0.06	0.28	0.03	0.20
OCT T	0.10	0.06	-0.04	0.25	0.02	0.17	-0.17	-0.09	0.14	0.19	-0.14	0.16	-0.03	0.06	0.02	0.32	0.15	0.36	-0.01	0.25
NOV T	0.13	0.07	0.09	0.06	0.05	0.01	0.00	-0.17	0.00	0.18	0.00	0.04	0.06	-0.01	-0.07	0.13	0.08	0.03	0.05	0.09
DEC T	-0.08	-0.12	-0.07	0.07	-0.01	0.00	-0.03	-0.16	-0.11	0.21	-0.15	-0.04	-0.04	-0.07	-0.11	0.29	-0.03	0.19	-0.01	-0.08
Jan T	0.16	0.02	0.08	0.15	0.02	-0.09	0.08	-0.07	-0.22	-0.01	0.01	-0.13	0.11	-0.06	0.05	0.04	-0.03	-0.12	0.15	-0.13
Feb T	0.08	-0.01	0.05	0.02	0.02	-0.17	0.09	-0.01	-0.20	0.11	0.03	-0.20	0.09	-0.12	0.04	-0.15	-0.09	-0.13	0.19	-0.13
Mar T	0.04	0.00	-0.06	0.06	-0.05	-0.13	0.03	-0.02	-0.08	0.15	0.04	0.05	-0.02	-0.02	-0.18	-0.02	0.03	0.09	0.05	-0.03
Apr T	-0.10	-0.21	-0.26	-0.08	-0.17	-0.24	-0.10	-0.06	-0.18	-0.02	-0.23	-0.11	-0.22	-0.27	-0.26	0.12	-0.04	0.07	-0.12	-0.16
May T	0.11	0.07	-0.11	0.17	-0.06	-0.03	0.08	0.13	-0.05	0.15	-0.09	0.12	-0.04	0.01	-0.10	0.10	0.04	0.19	0.03	0.03
Jun T	0.26	-0.05	0.01	0.05	0.08	-0.01	0.03	-0.02	0.24	0.16	0.06	0.14	0.05	0.08	0.02	0.34	0.11	0.21	0.18	0.10
Jul T	0.52	0.38	0.39	0.32	0.40	0.26	0.42	0.30	0.31	0.40	0.38	0.22	0.42	0.36	0.26	0.26	0.28	0.24	0.29	0.26
Aug T	0.11	-0.14	-0.06	-0.07	-0.06	-0.03	-0.22	-0.21	0.08	0.04	-0.07	-0.17	-0.09	-0.19	0.06	0.29	0.03	0.18	0.09	0.21
Sep T	0.26	-0.03	-0.02	0.07	0.04	0.06	-0.18	-0.15	0.40	0.18	-0.01	0.02	0.01	-0.01	0.08	0.37	0.15	0.40	0.06	0.33

Table 4- The number of months that Cartwright’s mean monthly temperature illustrated significant correlations to annual radial growth at a 99% significance threshold in a response function analysis performed by program DENDROCLIM2002. The cells highlighted in black have a positive relationship above the 99% confidence threshold. The cells highlighted in grey have a negative correlation above the 99% confidence threshold.

	W1S	W1F	W2S	W2F	W3S	W3F	W4S	W4f	C1W	C1F	C2S	C2F	C3S	C3F	C4S	C4L	E3S	E3F	E4S	E4F
APR T	-0.10	-0.26	-0.13	-0.09	-0.10	-0.19	-0.12	-0.12	0.02	-0.10	-0.12	-0.16	-0.16	-0.16	-0.15	0.01	-0.11	0.00	-0.10	-0.24
MAY T	0.02	-0.15	-0.03	0.11	0.04	-0.06	-0.02	-0.05	-0.06	-0.08	-0.13	-0.03	-0.02	-0.02	-0.10	0.09	-0.16	0.04	-0.19	-0.20
JUN T	0.07	-0.18	-0.05	0.03	0.04	-0.03	-0.01	-0.19	-0.12	0.08	-0.08	-0.11	-0.01	-0.11	-0.08	0.26	-0.05	0.00	0.05	-0.19
JUL T	0.37	0.21	0.32	0.24	0.34	0.20	0.35	0.10	0.00	0.21	0.34	0.03	0.37	0.19	0.23	0.21	0.22	0.07	0.14	0.04
AUG T	0.01	-0.31	-0.12	-0.12	-0.07	-0.13	-0.19	-0.29	0.00	-0.12	-0.17	-0.15	-0.10	-0.32	-0.05	0.29	-0.09	0.23	-0.05	0.08
SEP T	0.10	-0.20	0.00	0.04	0.04	0.04	-0.19	-0.32	0.22	-0.02	-0.16	-0.15	0.01	-0.15	0.10	0.40	0.06	0.28	0.03	0.20
OCT T	0.10	0.06	-0.04	0.25	0.02	0.17	-0.17	-0.09	0.14	0.19	-0.14	0.16	-0.03	0.06	0.02	0.32	0.15	0.36	-0.01	0.25
NOV T	0.13	0.07	0.09	0.06	0.05	0.01	0.00	-0.17	0.00	0.18	0.00	0.04	0.06	-0.01	-0.07	0.13	0.08	0.03	0.05	0.09
DEC T	-0.08	-0.12	-0.07	0.07	-0.01	0.00	-0.03	-0.16	-0.11	0.21	-0.15	-0.04	-0.04	-0.07	-0.11	0.29	-0.03	0.19	-0.01	-0.08
Jan T	0.16	0.02	0.08	0.15	0.02	-0.09	0.08	-0.07	-0.22	-0.01	0.01	-0.13	0.11	-0.06	0.05	0.04	-0.03	-0.12	0.15	-0.13
Feb T	0.08	-0.01	0.05	0.02	0.02	-0.17	0.09	-0.01	-0.20	0.11	0.03	-0.20	0.09	-0.12	0.04	-0.15	-0.09	-0.13	0.19	-0.13
Mar T	0.04	0.00	-0.06	0.06	-0.05	-0.13	0.03	-0.02	-0.08	0.15	0.04	0.05	-0.02	-0.02	-0.18	-0.02	0.03	0.09	0.05	-0.03
Apr T	-0.10	-0.21	-0.26	-0.08	-0.17	-0.24	-0.10	-0.06	-0.18	-0.02	-0.23	-0.11	-0.22	-0.27	-0.26	0.12	-0.04	0.07	-0.12	-0.16
May T	0.11	0.07	-0.11	0.17	-0.06	-0.03	0.08	0.13	-0.05	0.15	-0.09	0.12	-0.04	0.01	-0.10	0.10	0.04	0.19	0.03	0.03
Jun T	0.26	-0.05	0.01	0.05	0.08	-0.01	0.03	-0.02	0.24	0.16	0.06	0.14	0.05	0.08	0.02	0.34	0.11	0.21	0.18	0.10
Jul T	0.52	0.38	0.39	0.32	0.40	0.26	0.42	0.30	0.31	0.40	0.38	0.22	0.42	0.36	0.26	0.26	0.28	0.24	0.29	0.26
Aug T	0.11	-0.14	-0.06	-0.07	-0.06	-0.03	-0.22	-0.21	0.08	0.04	-0.07	-0.17	-0.09	-0.19	0.06	0.29	0.03	0.18	0.09	0.21
Sep T	0.26	-0.03	-0.02	0.07	0.04	0.06	-0.18	-0.15	0.40	0.18	-0.01	0.02	0.01	-0.01	0.08	0.37	0.15	0.40	0.06	0.33

Figure captions

Figure 1 - Labrador with the sample nodes and the associated three north-south columns of sites (W= west C= central and E= east). These placements represent the theorectical placement of sample nodes. The exact nodes where selected within a 5 minute radius of these points (with the exception of C4 which extented the radius to accommodate its location over the Atlantic Ocean).

Figure 2 – Average mean monlthy tempertures in degrees Celcius for the entire instrumental record of the Goose Bay (#71816) and Cartright (#71818) Environment Canada stations.

Figure 3 - The radial-growth response to mean monthly tempertures at Cartwright. The graphs are arranged spatially to represent each node. Each graph has dotted lines to indicate 95% significance and solid lines to indicated 99% signifcance. The black bars indicate the black or white spruce relationship at a node, while the grey bars indicate balsam fir or eastern larch relationships at a node.

Figure 4 – Labrador with approximate boundaries of the three zones of the radial growth-climate relationships. The continental and western part of the maritime zone were defined by Nishimura (2009), while the extension of the maritime zone eastward, and the delineation of the hyper-maritime zone is from this study.

Figures

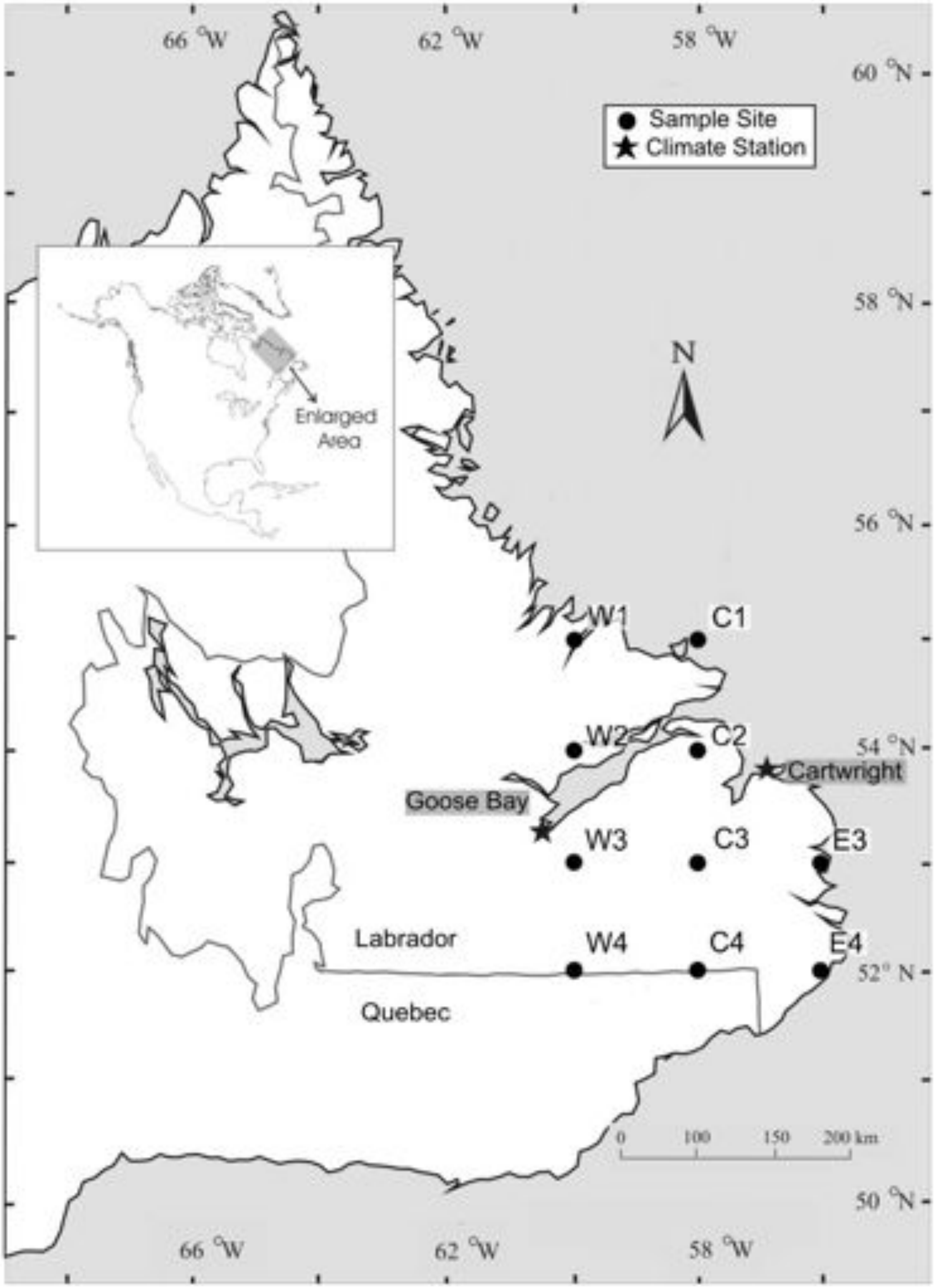
66 °W
62 °W
58 °W
60 °N
58 °N
56 °N
54 °N
52° N
50 °N
● Sample Site
★ Climate Station
N
Enlarged Area
W1
C1
W2
C2
Cartwright
Goose Bay
W3
C3
E3
Labrador
W4
C4
E4
Quebec
0
100
150
200 km

Figure 1

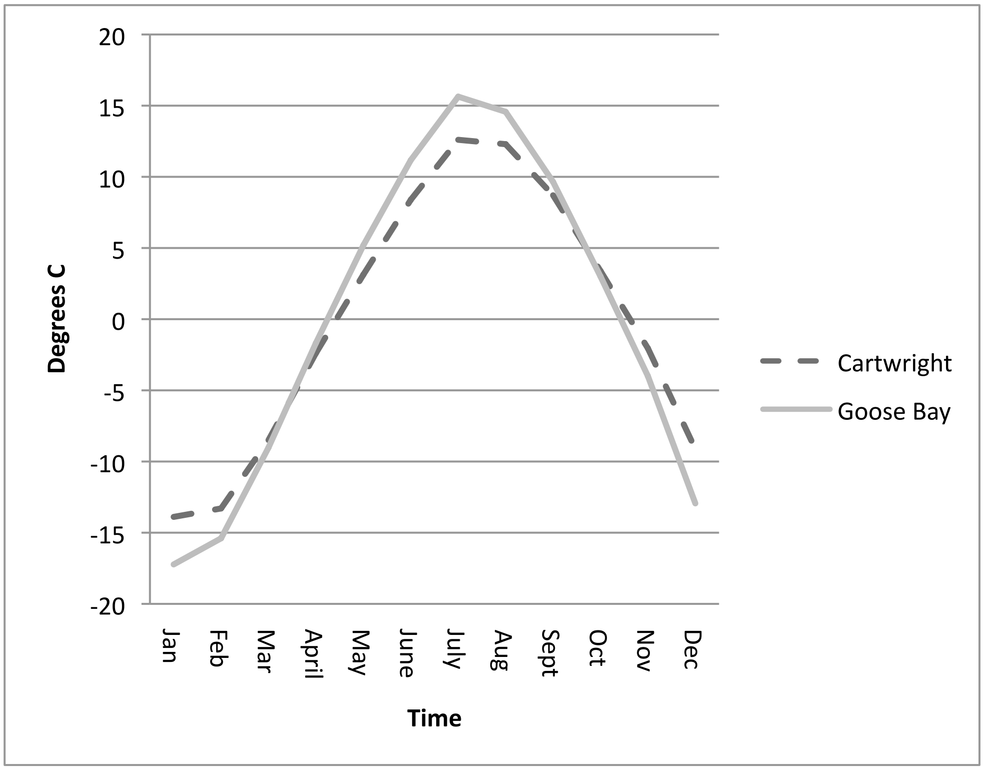

Figure 2

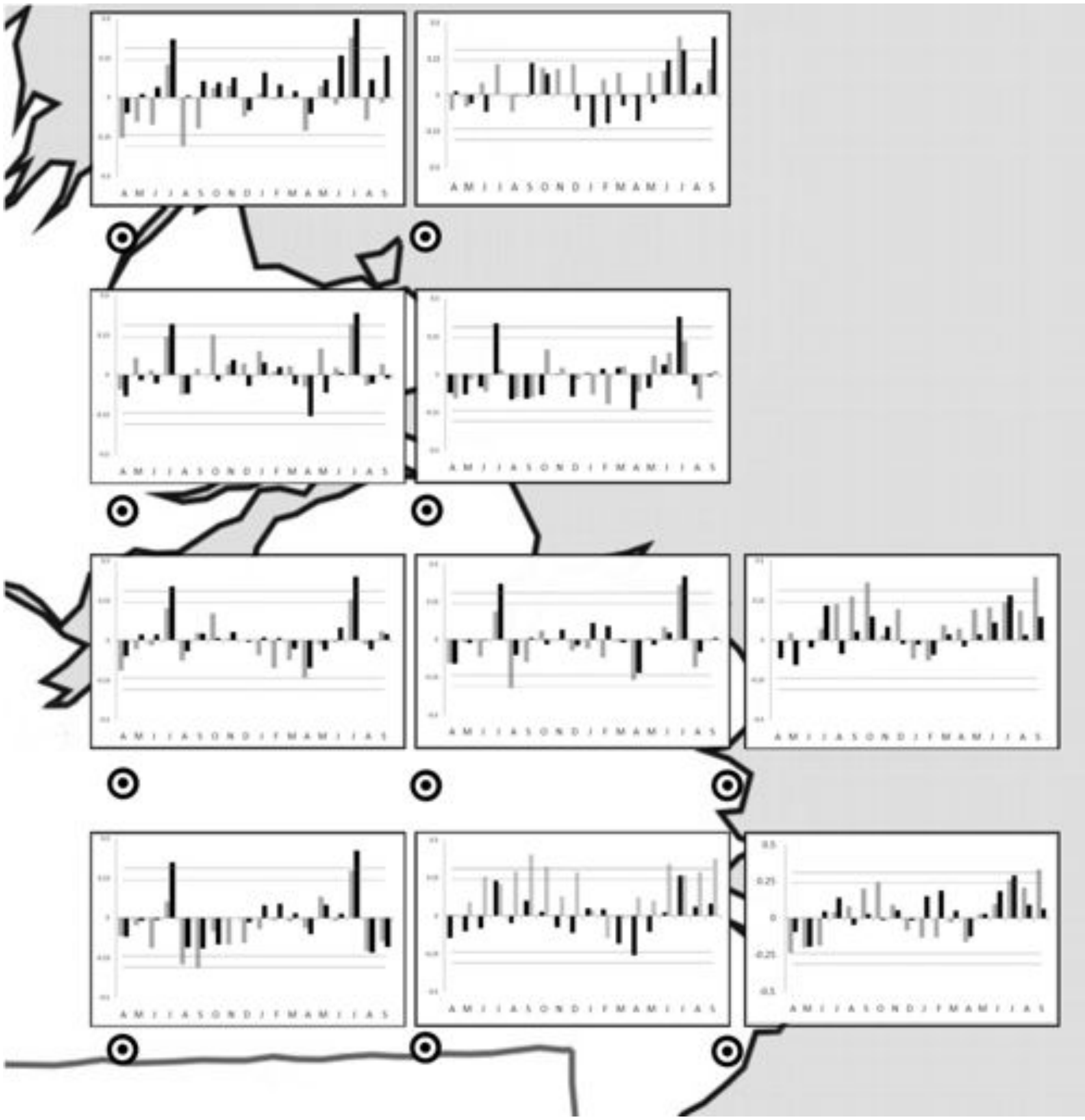

Figure 3

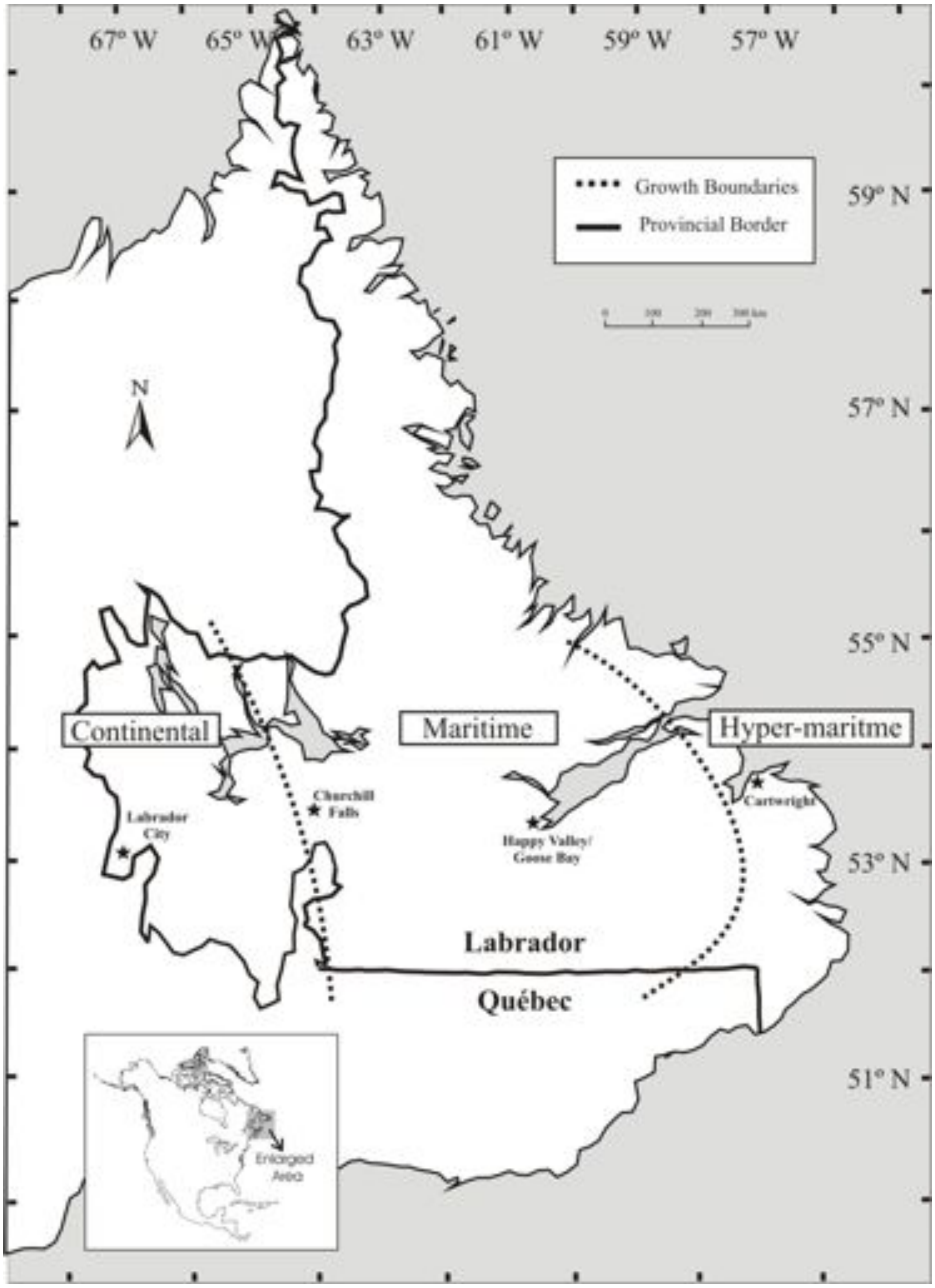
67° W
65° W
63° W
61° W
59° W
57° W
59° N
57° N
55° N
53° N
51° N
Growth Boundaries
Provincial Border
0
100
200
300 km
N
Continental
Maritime
Hyper-maritme
Churchill Falls
Labrador City
Happy Valley/ Goose Bay
Cartwright
Labrador
Québec
Enlarged Area

Figure 4